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Original Communication

Pulmonary intra-alveolar hemorrhage in SIDS and suffocation

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Abstract

The differentiation of SIDS from accidental or inflicted suffocation may be impossible in some cases. Severe pulmonary intra-alveolar hemorrhage has been suggested as a potential marker for such differentiation. Our aims are to: (1) Compare pulmonary hemorrhage in SIDS and a control group comprised of infants whose deaths were attributed to accidental or inflicted suffocation. (2) Review individual cases with the most severe pulmonary hemorrhage regardless of the cause of death, and (3) Assess the effect of age, bedsharing, cardiopulmonary resuscitation, and postmortem interval, with regard to the severity of pulmonary hemorrhage in SIDS cases. We conducted a retrospective study of all postneonatal cases accessioned by the Office of the Medical Examiner in San Diego County, California who died of SIDS or suffocation between 1999 and 2004. A total of 444 cases of sudden infant death caused by SIDS (405), accidental suffocation (36), and inflicted suffocation (3) from the San Diego SIDS/SUDC Research Project database were compared using a semiquantitative measure of pulmonary intra-alveolar hemorrhage [absent (0) to severe (4)]. Grades 3 or 4 pulmonary hemorrhage occurred in 33% of deaths attributed to suffocation, but in only 11% of the SIDS cases, however, all grades of pulmonary hemorrhage occurred in both groups. Therefore, our results indicate that the severity of pulmonary hemorrhage cannot be used in isolation to determine the cause or manner of sudden infant death. Among SIDS cases, those with a higher pulmonary hemorrhage grade (3 or 4) were more likely to bedshare, and with more than one co-sleeper, than those with a lower pulmonary hemorrhage grade (0 or 1). We conclude that each case must be evaluated on its own merits after thorough review of the medical history, circumstances of death, and postmortem findings.

Keywords: Pulmonary hemorrhage; SIDS; Infanticide; Sudden infant death; Suffocation; Oronasal blood; Child protective services

1. Introduction

Sudden infant death syndrome (SIDS) is generally defined as the sudden unexpected death of an infant less than one year of age, with onset of the fatal episode apparently occurring during sleep, that remains unexplained after a thorough case investigation, including performance of a complete autopsy and review of the circumstances of death and the clinical history.[1] As such, SIDS remains a diagnosis of exclusion. Nevertheless, there are cases in which SIDS cannot be differentiated from accidental or inflicted suffocation by postmortem examination alone when postmortem findings are minimal, and none are considered pathognomonic of a cause of death. This is particularly true in cases of "soft" suffocation where anatomic findings diagnostic of oronasal occlusion or chest compression are not identified during the postmortem examination. This difficulty has led to subsequent reclassification of some SIDS cases to either accidental or inflicted suffocation after re-evaluation of the circumstances of death.[2–7] Ultimately, differentiating SIDS from accidental or inflicted suffocation may be impossible in the absence of a convincing demonstration of an unsafe sleep site in the case of the

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former or a reliable confession in the case of the latter. Therefore, investigators have continued to search for postmortem markers, such as pulmonary hemorrhage, that might reliably distinguish these cases, especially given the substantial legal consequences and ramifications for survivors.

Severe pulmonary hemorrhage and/or pulmonary intra-alveolar siderophages have been proposed previously as morphologic markers to aid in distinguishing SIDS from "soft" suffocation.[1,8–13] Our previous analysis of infants dying of SIDS or accidental or inflicted suffocation who were accessioned into the San Diego SIDS/SUDC Research Project database has shown that pulmonary siderophages (PS) cannot be used as an independent marker to distinguish SIDS from suffocation.[14] The aims of this study are to: (1) Compare pulmonary hemorrhage in SIDS and a control group comprised of infants whose deaths were attributed to accidental or inflicted suffocation. (2) Review the individual cases with the most severe pulmonary hemorrhage regardless of the cause of death, and (3) Assess the effect of age, bedsharing, cardiopulmonary resuscitation, and postmortem interval on the severity of pulmonary hemorrhage in SIDS cases.

2. Materials and methods

This study was approved by the Rady Children's Hospital and Health Center Institutional Review Board. Postneonatal infants (29–365 days of age) accessioned by the San Diego County, California, Medical Examiner's Office between 1991 and 2004 whose deaths were attributed to SIDS or accidental or inflicted suffocation were selected from the San Diego SIDS and Sudden Unexplained Death in Childhood Research Project database located in the Pathology Department of Rady Children's Hospital and Health Center in San Diego, California. Infants with only one lung section for microscopic review, or whose causes of death were other natural diseases or undetermined were excluded, as were cases whose deaths were delayed and cases who underwent more than three hours of continuous cardiopulmonary resuscitation.

Case data were selected from the medical history, death scene, and postmortem information in the investigative and autopsy reports and from two standardized data protocols for the death scene investigation and postmortem examination. In 1989, a California statute mandated use of standardized scene investigation and postmortem examination protocols (developed by a multidisciplinary expert committee) for cases of sudden, unexpected infant death without external evidence of inflicted injuries. Trained, experienced investigators from the Medical Examiner are charged with collecting this information within 30 h of an infant's death. The data are not complete for every case.

A diagnosis of SIDS was made only when criteria for the general definition proposed in 2004 in San Diego were fulfilled.[1] Cases of accidental or inflicted suffocation were diagnosed upon analysis of information obtained from the medical histories, circumstances of death, and postmortem findings.

For purposes of this study a total of 444 cases were included: SIDS, 405 cases; accidental suffocation, 36 cases; and inflicted suffocation, 3 cases. Since the mechanism of death was similar, the 39 cases of accidental and inflicted suffocation were combined into a single control group for comparison with the SIDS cases. These 39 control cases represent all of the accidental or inflicted suffocation deaths accessioned by the San Diego County Office of the Medical Examiner during the period of 1991–2004 for which at least two lung sections were available for microscopic review. At least two microscopic sections of the lung(s) were available for evaluation on 39/40 (98%) of control cases and 96% (405/423) of SIDS cases within this time frame.

As part of a separate report,[15] we have data on Child Protective Services referrals and their adjudication for cases from 1991 through 2000 only. Child Protective Services data for cases beyond the year 2000 are not available because our study had Institutional Review Board approval to review cases only through the year 2000.

Presence or absence of oronasal blood exuding from the nose and/or mouth, as described by the first person to discover the infant before the onset of cardiopulmonary resuscitation,[16] was compared between the SIDS and suffocation control groups. We reviewed frank oronasal blood, as opposed to the description of any other secretions (for example: purge, pink froth, bloody froth, vomitus, formula). The presence and distribution of intrathoracic petechiae were recorded from the postmortem records.

The postmortem interval was defined as the interval from the date and time the infant was pronounced dead until the date and time the postmortem examination was begun; as such, it is an underestimate, given that most of these infants were dead for some time before being discovered.

Pulmonary intra-alveolar hemorrhage was semiquantitatively assessed in hematoxylin and eosin (H&E) stained sections of formalin-fixed lung using the following grading system: grade 0 = none; 1 = mild; 2 = moderate, focal; 3 = moderate, multifocal; and 4 = diffuse, severe.

3. Data analysis

SIDS and suffocation control cases were compared to one another with respect to medical history, circumstances of death, and postmortem findings. Categorical variables were analyzed using the χ^2 test or Fisher's exact test, along with odds ratios. Continuous data were analyzed with two-sample *t*-tests and are summarized using means ± standard deviations. Calculations were performed with SPSS Version 12.0. A *P* value less than .05 was considered significant.

4. Results

4.1. Comparison of SIDS and control cases

The mean numbers of microscopic sections of the lungs for the SIDS and suffocation control cases were 4.6 ± 1.3 and 4.4 ± 1.3, respectively, and the ranges for the two groups were 2–11 and 2–7, respectively. There was one physician (HFK) who reviewed and evaluated slides for pulmonary hemorrhage and the intra-observer reproducibility testing corresponds to a κ-value of 0.90.

Table 1 lists the cause and manner of death for the 444 cases, 91% of which were SIDS. Table 2 compares the SIDS group to the Control cases. Fig. 1 illustrates the age distribution of these two groups. The SIDS and suffocation control groups were not significantly different with respect to gestational or postnatal age, or birth weight. Oronasal blood prior to cardiopulmonary resuscitation was noted significantly more often in the suffocation control group than in the SIDS group (18% suffocation controls, 5% SIDS; OR 0.26, 95% confidence interval 0.1, 0.74). The mean postmortem interval for the two groups was similar (22.6 h for SIDS vs. 22.9 h for controls). Intrathoracic petechiae were found with comparable frequency

Table 1
Manner and cause of death for 444 cases of sudden infant death

Manner	Cause of death	Number	Total cases
Natural	SIDS		405
Accident	Suffocation		36
	Positional	16	
	Mechanical	9	
	Overlay	11	
Homicide	Suffocation		3

Table 2
SIDS vs. suffocation

	SIDS ($n = 405$)	Suffocation ($n = 39$)	*P*	Odds ratio (95% CI)
Age (days)			NS	
Range	29–326	32–324		
Mean ± SD	102 ± 58	121 ± 74		
Gender			NS	
Male	246 (61%)	24 (62%)		
Female	159 (39%)	15 (38%)		
Gestation	$n = 348$	$n = 29$	NS	
Full term	253 (73%)	23 (79%)		
Premature	95 (27%)	6 (21%)		
Delivery	$n = 343$	$n = 29$	NS	
Vaginal	257 (75%)	23 (79%)		
Cesarean	86 (25%)	6 (21%)		
Birthweight (g)	$n = 316$	$n = 29$	NS	
Range	454–4791	1361–4990		
Mean ± SD	3030 ± 783	3135 ± 788		
Median	3175	2980		
Oronasal blood[b]	22 of 405 (5%)	7 of 39 (18%)	.008	0.26 (0.1, 0.74)
CPR[c] performed	335 of 400 (84%)	37 of 39 (95%)	NS	
Mean CPR ± SD (min)	38.9 ± 27.5	40.8 ± 21.7	NS	
CPR duration	$n = 327$	$n = 37$		
<30 min	127 (39%)	10 (27%)		
30–60 min	151 (46%)	23 (62%)		
>60 min	49 (15%)	4 (11%)		
PMI[d] range (h)	3.9–51	4.5–49		
Mean PMI ± SD (h)	22.6 ± 7	22.9 ± 8.1	NS	
Intrathoracic petechiae	348 of 405 (86%)	32 of 39 (82%)	NS	
Pulmonary hemorrhage grade[a]				
0	113 (28%)	6 (15%)	.01	
1	160 (40%)	15 (38%)		
2	86 (21%)	5 (13%)		
3	31 (8%)	8 (21%)		
4	15 (4%)	5 (13%)		

CI, confidence interval.
[a] Pulmonary hemorrhage semiquantitative grade: 0 = none; 1 = mild; 2 = moderate, focal; 3 = moderate, multifocal; 4 = diffuse, severe.
[b] Oronasal blood is defined here as overt blood (vs. other oronasal secretions such as bloody or serosanguinous froth, mucus or emesis) observed on the infant's nose or mouth at the time of discovery.
[c] CPR, cardiopulmonary resuscitation.
[d] Postmortem interval (PMI): time elapsed between pronounced death and commencement of autopsy.

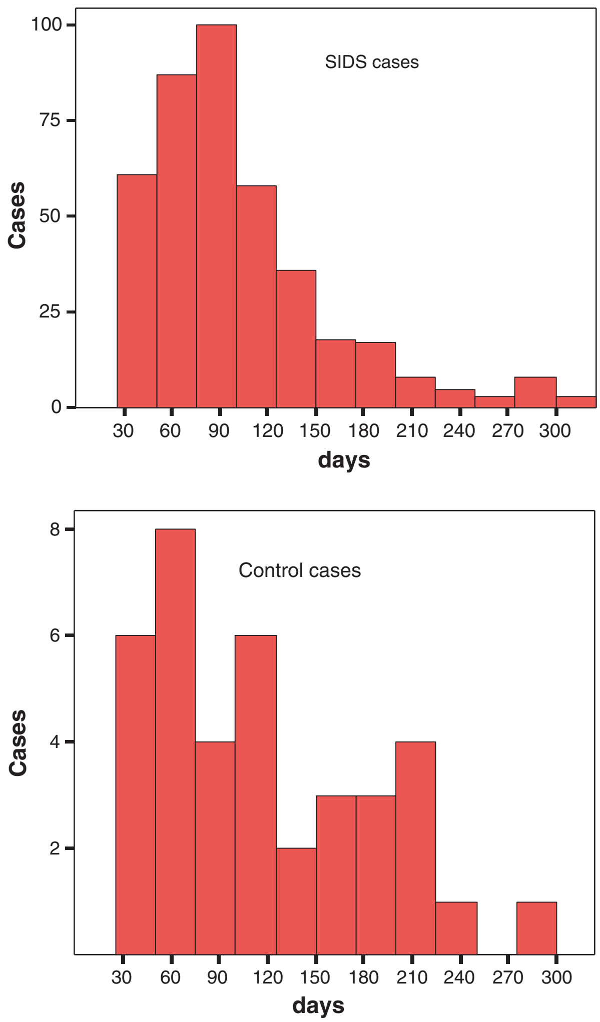

Fig. 1. Histogram of age for SIDS and suffocation control cases.

in both groups (86% for SIDS and 82% for controls). Although the majority of cases in both groups underwent cardiopulmonary resuscitation, it was attempted significantly less often in SIDS cases than suffocation control cases (82% vs. 95%, respectively, $P < .05$). The mean duration of cardiopulmonary resuscitation, however, was similar (38.9 min for SIDS vs. 40.8 min for Controls). Only five cases underwent cardiopulmonary resuscitation for $\geqslant 2$ h and all were SIDS; the severity of pulmonary hemorrhage ranged from grade 0 to 2 for these five cases.

Table 3 compares the SIDS group to the control group by grade of pulmonary hemorrhage. The percentage of SIDS cases described with oronasal blood steadily increased from 2% (2 of 113 cases) with grade 0 to 13% (2 of 15 cases) with grade 4 pulmonary hemorrhage. Across all grades of pulmonary hemorrhage, SIDS cases were less likely to have attempts at cardiopulmonary resuscitation compared to the control group (73–90% vs. 88–100%, respectively). Excepting grade 4 pulmonary hemorrhage, a larger proportion of controls bedshared compared to SIDS infants.

Two-thirds (67%) of the cases in the SIDS group had either grade 0 or grade 1 pulmonary hemorrhage compared to 54% of the control group. In contrast, Grade 3 or 4 pulmonary hemorrhage occurred in only 11% of SIDS compared to 33% of the control cases. The control cases had a bimodal distribution, with 59% having either grade 1 or 3 pulmonary hemorrhage (Tables 2 and 3). Especially noteworthy is the fact that pulmonary hemorrhage ranged from grade 0 to 4 in both groups (Tables 2 and 3).

Data regarding Child Protective Services referral histories were available for 99% (325 of 329) of the SIDS cases and 97% (28 of 29) of control cases for the years 1991–2000; 38 (12%) SIDS infants had at least one referral in the year prior to death, compared to two infants in the control group (7%). Fifteen (39%) of the 38 SIDS infants had a substantiated referral; one infant in the control group had a substantiated referral. Almost one-third (30% of SIDS families and 32% of families of control group infants) of both groups was found to have at least one referral to Child Protective Services within five years prior to the infant's death.

4.2. Pulmonary hemorrhage in SIDS

Table 3 shows that as the severity of pulmonary hemorrhage increases from grade 0 to 4, the mean age decreases from 111 days to 82 days. Bedsharing occurred in a higher percentage of SIDS cases with higher grades of pulmonary hemorrhage: 45% (20 of 44) of cases with grade 3 or 4 pulmonary hemorrhage compared to only 24% (63 of 264) of SIDS cases with grade 0 or 1 pulmonary hemorrhage (Table 3).

The effect of age was evaluated by dividing the SIDS cases into two groups: those younger ($\leqslant$91 days) or older than 13 weeks (>91 days). This shows a similar distribution of the severity of pulmonary hemorrhage within SIDS with respect to age being $\leqslant$13 or >13 weeks (Fig. 2). Age was found to have no effect on the severity of pulmonary hemorrhage when SIDS cases were bedsharing (Fig. 3).

Table 4 shows that 73% (167 of 229) of the cases with grade 0 or 1 pulmonary hemorrhage were found prone; in contrast, 56% (23 of 41) cases with grade 3 or 4 pulmonary hemorrhage were found prone. Forty-two percent (81 of 195) of SIDS cases with grade 0 or 1 pulmonary hemorrhage were found face down compared to only 33% (11 of 33) with grade 3 or 4 pulmonary hemorrhage.

4.3. Cases with severe pulmonary hemorrhage

The characteristics of all cases ($n = 20$) with grade 4 pulmonary hemorrhage, regardless of the cause of death, are shown in Table 5. The ages ranged from 30 to 284 days. None died from inflicted suffocation; five were victims of accidental suffocation. Three (15%) of these 20 cases were found with oronasal blood; two died of SIDS and the other of positional suffocation. Eighty percent (16/20) had intrathoracic petechiae; the four without

Table 3
Pulmonary hemorrhage severity in SIDS and suffocation

	Pulmonary hemorrhage grade[a]									
	0		1		2		3		4	
	SIDS ($n = 113$)	Suffocation ($n = 6$)	SIDS ($n = 160$)	Suffocation ($n = 15$)	SIDS ($n = 86$)	Suffocation ($n = 5$)	SIDS ($n = 31$)	Suffocation ($n = 8$)	SIDS ($n = 15$)	Suffocation ($n = 5$)
Average age ± SD	111 ± 62	150 ± 73	102 ± 58	117 ± 90	95 ± 48	156 ± 76	95 ± 64	110 ± 58	82 ± 66	84 ± 34
Bedsharing	26 of 110 (24%)	2 of 5 (40%)	37 of 154 (24%)	10 of 15 (67%)	22 of 86 (26%)	3 of 4 (75%)	13 of 29 (45%)	4 of 8 (50%)	7 of 15 (47%)	2 of 5 (40%)
>1 Bedsharer	10 of 26 (38%)	1 of 2 (50%)	11 of 37 (30%)	5 of 10 (50%)	11 of 21 (52%)	2 of 3 (66%)	7 of 13 (54%)	1 of 4 (25%)	3 of 7 (43%)	0
Between bedsharers	5 of 9 (56%)	1 of 1 (100%)	5 of 11 (45%)	1 of 5 (20%)	6 of 8 (75%)	1 of 1 (100%)	1 of 4 (25%)	1 of 1 (100%)	1 of 2 (50%)	
Oronasal blood[b]	2 of 113 (2%)	1 of 6 (17%)	8 of 160 (5%)	4 of 15 (27%)	7 of 86 (8%)	0 of 5	3 of 31 (10%)	1of 8 (13%)	2 of 15 (13%)	1 of 5 (20%)
Intrathoracic petechiae	94 of 113 (83%)	4 of 6 (67%)	141 of 160 (88%)	11 of 15 (73%)	77 of 86 (90%)	5 of 5 (100%)	25 of 31 (81%)	7 of 8 (88%)	11 of 15 (73%)	5 of 5 (100%)
CPR[c] Performed	86 of 111 (77%)	6 of 6 (100%)	134 of 157 (85%)	14 of 15 (93%)	76 of 86 (88%)	5 of 5 (100%)	28 of 31 (90%)	7 of 8 (88%)	11 of 15 (73%)	5 of 5 (100%)
CPR duration	$n = 84$	$n = 6$	$n = 130$	$n = 14$	$N = 74$	$n = 5$	$n = 28$	$n = 7$	$n = 11$	$n = 5$
<30 min	40 (48%)	1 (17%)	53 (41%)	6 (43%)	24 (32%)	2 (40%)	7 (25%)	1 (14%)	3 (27%)	–
30–60 min	32 (38%)	5 (83%)	59 (45%)	7 (50%)	38 (51%)	–	16 (57%)	6 (86%)	6 (55%)	5 (100%)
>60 min	12 (14%)	–	18 (14%)	1 (7%)	12 (16%)	3 (60%)	5 (18%)		2 (18%)	–
Mean CPR ± SD (min)	38.0 ± 31.1	40.5 ± 16.9	38.1 ± 27.7	35.5 ± 24.2	40.1 ± 26.4	51.6 ± 36.3	40.6 ± 20.6	40.3 ± 11	44.4 ± 18.6	45.6 ± 14
PMI[d] range (h)	4.3–49.1	10.1–27.5	3.9–50.8	19.5–48.8	5.8–50	4.5–29.2	4–51	7.9–27.3	16.7–29.5	18.8–28.9
Mean PMI ± SD (h)	22.1 ± 7.4	21.9 ± 7	22.1 ± 6.8	27.5 ± 6.9	24 ± 6.5	17.9 ± 10.6	22.6 ± 8.4	17.8 ± 7.8	24 ± 4.3	23.1 ± 3.7

[a] Pulmonary hemorrhage semiquantitative grade: 0 = none; 1 = mild;2 = moderate, focal; 3 = moderate, multifocal; 4 = diffuse, severe.
[b] Oronasal blood is defined here as overt blood (vs. other oronasal secretions such as bloody or serosanguinous froth, mucus or emesis) observed on the infant's nose or mouth at the time of discovery.
[c] CPR: Cardiopulmonary resuscitation.
[d] Postmortem interval (PMI): time elapsed between pronounced death and commencement of autopsy.

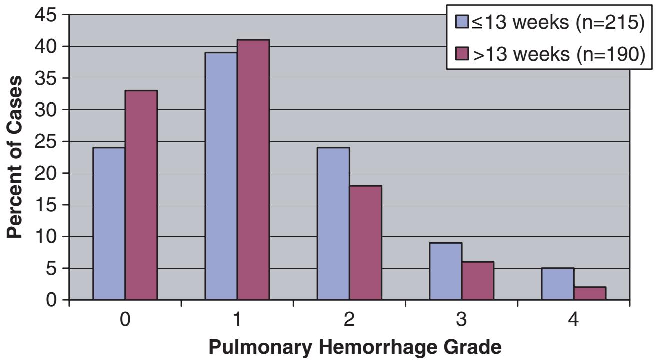

Fig. 2. Pulmonary hemorrhage in SIDS by age.

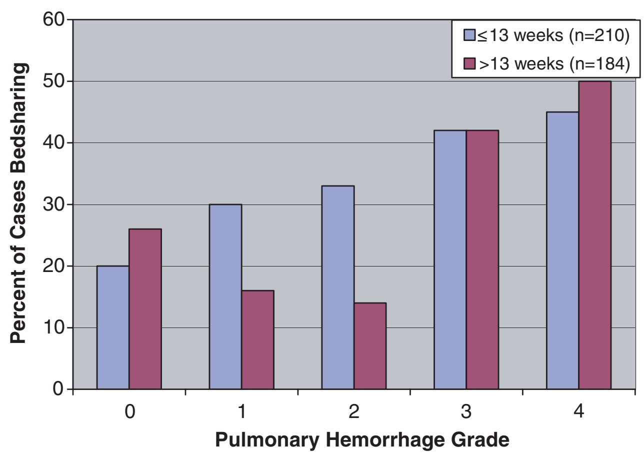

Fig. 3. Pulmonary hemorrhage and bedsharing status (these data represent the 97% of SIDS cases for which bedsharing status was known) in SIDS by age group.

intrathoracic petechiae were all SIDS cases. Only one of 14 families for which data were available was referred to Child Protective Services during the five years prior to the infant's death; the infant (case J) died of accidental suffocation and the family had been referred previously for caretaker absence and incapacity (the referral was adjudicated as inconclusive).

5. Discussion

The existent literature regarding the significance of pulmonary hemorrhage in SIDS and non-SIDS is contradictory as a result of inconsistent inclusion criteria, absence of control cases and lack of uniformity of assessment of pulmonary hemorrhage across studies.[9,10,13,17–19] Becroft et al. suggested that pulmonary hemorrhage might be more frequent in infant deaths caused by accidental or inflicted suffocation than in deaths caused by SIDS, but the lack of control cases limits their study.[9] Potter et al. observed more severe pulmonary hemorrhage in infants dying of accidental or inflicted suffocation than SIDS but their data have been presented only as an abstract.[19]

5.1. SIDS and suffocation control cases

The mean ages of the SIDS and suffocation control groups were not significantly different although the majority of the SIDS cases occurred between the ages of 30 and 180 days compared to control cases whose ages were more evenly distributed between 30 and 330 days (Fig. 1). Approximately 60% of both groups were male, and approximately three quarters of both groups were born at term gestation and a similar proportion was delivered vaginally.

Even though the distribution of the severity of pulmonary hemorrhage was significantly different between our SIDS and control groups ($P = .01$, Table 2), our data reveal that the severity of pulmonary hemorrhage as an isolated finding will not distinguish cases of SIDS from suffocation, whether accidental or inflicted. Although pulmonary hemorrhage is more often absent or of mild severity in SIDS compared to suffocation control cases, there are SIDS cases in which pulmonary hemorrhage is severe and diffuse, just as there are suffocation cases with absent or very mild pul-

Table 4
Body position by pulmonary hemorrhage grade in SIDS

	Pulmonary hemorrhage grade[a]				
	0 ($n = 113$)	1 ($n = 160$)	2 ($n = 86$)	3 ($n = 31$)	4 ($n = 15$)
Placed body position	$n = 79$	$n = 116$	$n = 67$	$n = 24$	$n = 9$
Prone	57 (72%)	67 (57%)	25 (37%)	10 (42%)	3 (33%)
Side	7 (9%)	17 (14%)	21 (31%)	8 (33%)	2 (22%)
Supine	15 (19%)	32 (27%)	21 (31%)	6 (25%)	4 (44%)
Found body position	$n = 98$	$n = 131$	$n = 72$	$n = 28$	$n = 13$
Prone	81 (83%)	86 (66%)	36 (50%)	13 (46%)	10 (77%)
Side	6 (6%)	17 (13%)	14 (19%)	7 (25%)	1 (8%)
Supine	11 (11%)	28 (21%)	22 (31%)	8 (29%)	2 (15%)
Found face position	$n = 82$	$n = 113$	$n = 62$	$n = 23$	$n = 10$
Down	41 (50%)	40 (35%)	19 (31%)	6 (26%)	5 (50%)
Side	35 (43%)	57 (50%)	29 (47%)	11 (48%)	5 (50%)
Up	6 (7%)	16 (14%)	14 (23%)	6 (26%)	–

[a] Pulmonary hemorrhage semiquantitative grade: 0 = none; 1 = mild; 2 = moderate, focal; 3 = moderate, multifocal; 4 = diffuse, severe.

Table 5
SIDS and suffocation cases with a pulmonary hemorrhage grade of 4

Case	Age (days)	Diagnosis	Gender	Bedsharing	Placed body position	Found body position	Found face position	Oronasal blood	Intra-thoracic petechiae	CPR duration (min)	PMI (h)
A	30	SIDS	M	Beside mother	Side	Prone	Down	N	Y	0	23.8
B	31	SIDS	F	N	U	U	U	N	Y	0	28.8
C	32	SIDS	M	Beside mother	U	Prone	Down	N	Y	26	26.5
D	42	SIDS	F	N	U	Prone	U	N	Y	30	26.5
E	42	SIDS	F	Beside mother	Supine	U	U	Y	Y	13	26.3
F	47	SIDS	M	Beside mother (on couch)	Supine	Supine	Side	N	Y	0	25.9
G	48	SIDS	M	Between parents	Supine	Supine	Side	N	N	0	29.5
H	49	SIDS	M	N	Side	Prone	Side	N	N	65	21
I	51	Mechanical suffocation ("bouncy seat" strap)	F	N	n/a	n/a	n/a	N	Y	53	24
J	58	Mechanical suffocation (plastic bag)	M	Beside mother	U	Prone	Down	N	Y	30	21.5
K	73	Positional suffocation (face down on pillow)	M	N	U	Prone	Down	Y	Y	54	22.6
L	82	SIDS	M	N	U	Prone	Down	N	Y	60	21.8
M	84	SIDS	F	N	U	Prone	Side/wedged	N	Y	25	27.6
N	88	SIDS	M	N	Prone	Prone	U	N	Y	45	16.7
O	103	SIDS	M	N	Prone	Prone	Down	Y	Y	45	21.6
P	115	Mechanical suffocation (plastic bag)	M	Beside mother	Supine	U	U	N	Y	31	28.9
Q	125	Positional suffocation (face down on stuffed animal)	F	N	Prone	U	U	N	Y	60	18.8
R	130	SIDS	F	Beside mother	U	Side	Side	N	Y	50	18
S	135	SIDS	M	N	Prone	Prone	Down	N	N	60	17.8
T	284	SIDS	M	With parents and sibling, position unknown	Supine	Prone	U	N	N	69	28.7

U, unknown.
F, female; M, male.
N, no; Y, yes.
CPR, cardiopulmonary resuscitation.
PMI, postmortem interval.

monary hemorrhage (Table 3). Grade 3 or 4 pulmonary hemorrhage occurred less often in SIDS compared to suffocation controls (11% vs. 33%). Interestingly, 15% of control cases had no pulmonary hemorrhage.

Oronasal blood has been identified with covert video surveillance after attempts at inflicted suffocation of living infants by their caretakers reported by Southall et al.,[20] and in many of the cases of unnatural sudden infant death reported by Meadow,[6] but only rarely in our SIDS cases found alone and supine in a safe sleep environment.[16] In our earlier study, oronasal blood was described in only 10 (3%) of 300 SIDS cases and in 2 (14%) of 14 accidental suffocation cases; eight of the 10 SIDS infants were bedsharing.[16] Becroft et al. reported oronasal blood in 15% of 385 cases of sudden infant death with a significant association with bedsharing.[9] In our current study, oronasal blood prior to the onset of cardiopulmonary resuscitation was described more than three times more frequently in the suffocation control group than the SIDS group [18% vs. 5% (OR .26, 95% CI 0.10, 0.74)], yet in these cases the severity of pulmonary hemorrhage ranged from grade 0 to 4 in both groups. As suggested in our earlier studies, oronasal blood likely arises from adjacent mucus membranes in contrast to pulmonary hemorrhage which arises from left ventricular failure.[21–23] There were four cases with grade 3 pulmonary hemorrhage and oronasal blood; three of these four had a family history of Child Protective Services referral within five years preceding the case infant's death; none of these referrals were substantiated. Thus, our data suggest that oronasal blood and pulmonary hemorrhage are independent findings, neither of which will reliably differentiate suffocation from SIDS.

Our data do not support the suggestion of Hanzlick that pulmonary hemorrhage is enhanced by attempts at cardiopulmonary resuscitation.[10] In our study, cardiopulmonary resuscitation was performed significantly more often among the controls than among SIDS cases ($P < .05$), but comparing cases without pulmonary hemorrhage to cases with diffuse, severe pulmonary hemorrhage reveals similar proportions of attempts at cardiopulmonary resuscitation within both groups (73% vs. 100% for SIDS and controls, respectively). Among our cases with grade 4 pulmonary hemorrhage, four had no cardiopulmonary resuscitation, whereas five received cardiopulmonary resuscitation for $\geqslant$60 min.

With respect to Hanzlick's suggestion that pulmonary hemorrhage may increase with increasing postmortem interval, our data show that within every grade of pulmonary hemorrhage there are postmortem intervals that exceed 27 h and some are as long as 51 h. This suggests that pulmonary hemorrhage is a consequence of underlying pathogenesis during the perimortem period.

5.2. Pulmonary hemorrhage in SIDS

Becroft et al. observed pulmonary hemorrhage significantly more often in infants <13 weeks of age.[9] In our study, infants $\leqslant$13 weeks of age had a larger proportion with grade 3 or 4 pulmonary hemorrhage compared to older infants (14% vs. 8%, $P < .004$), but grade 1 pulmonary hemorrhage predominated in both groups (Fig. 2), and the pulmonary hemorrhage ranged from absent to grade 4 in all ages of our SIDS cases.

Prone sleep position has been a long established risk factor for SIDS.[24–27] In our study, nearly three-quarters (73%) of our SIDS cases with grade 0 or 1 pulmonary hemorrhage were found prone compared to 56% of SIDS cases with grade 3 or 4 pulmonary hemorrhage (Table 4). Half (50%) of our SIDS cases with grade 0 pulmonary hemorrhage were found face down compared to 33% of cases with grade 3 or 4 pulmonary hemorrhage. If external airway obstruction or rebreathing into the surrounding microenvironment is related to the severity of pulmonary hemorrhage, then perhaps the position that the body, or more importantly the face, is *found* may be more relevant with respect to the potential mechanism of death.

Bedsharing is also known to increase the risk for SIDS,[28,29] therefore, its effect on the severity of pulmonary hemorrhage deserves comment. Among our cases, bedsharing was present in twice the percentage of SIDS cases with pulmonary hemorrhage grades 3 and 4 compared to those with pulmonary hemorrhage grades 0 or 1 (45% vs. 24%) (Table 3). These findings are difficult to explain. Accidental suffocation and/or hyperthermia caused by overlaying are mechanisms of death to consider in such cases, especially when the infant is found between two adult bedsharers. That less than half of the SIDS cases were bedsharing across all grades of pulmonary hemorrhage suggests more complex interactions at play.

We concur with the assertion of Yukawa et al. that there is no association between the extent of pulmonary hemorrhage and attempts, or lack thereof, at resuscitation.[13] Our data agree with an earlier study that found no significant relationship between the degree of pulmonary hemorrhage and the presence of intrathoracic petechiae.[9]

5.3. Limitations and strengths

The number of control cases is small ($n = 39$), but it includes every infant dying as a result of accidental or inflicted suffocation accessioned by the San Diego Medical Examiner during the study interval for which there were at least two microscopic sections of lung tissue. Our statistical analyses are limited since some data on gestation, delivery, birth weight, and perimortem circumstances, especially for the suffocation controls, are missing; the use of the standardized protocols is somewhat discretionary in cases of suffocation compared to SIDS where their use is mandated by California law. Like Becroft,[9] we reviewed nonstandardized lung sections. Although the International Standard Autopsy Protocol guidelines require at least one section per lung lobe in cases of sudden unexpected infant death, we included cases with at least two sections in order to have as large a control group as possible. Some

variables, such as body and face position when found, signify different circumstances for different groups, e.g., suffocation cases found with face to the side were often wedged between walls and furniture, with the airway obstructed. In SIDS cases, however, cases found with face to the side had no evidence of oronasal obstruction.

Conversely, our study has several unique strengths. It includes a larger number of SIDS and suffocation control cases than in previously published studies.[9,13,19] Data were collected using standardized California protocols within 30 h of each infant's sudden and unexpected death by trained and experienced investigators. Criteria from the most recent SIDS definition[1] were applied uniformly to all of the SIDS cases, which were then compared with infants who died of accidental or inflicted suffocation. To avoid confusion, we categorically excluded deaths caused by other natural diseases, such as pneumonia or sepsis that might contribute to pulmonary hemorrhage, as well as cases in which the cause and manner of death were unclassified sudden infant death[1] or undetermined. We omitted cases where cardiopulmonary resuscitation attempts were exceptionally prolonged, as well as cases in which death was delayed. Also, we reviewed cases, regardless of cause of death, with the most severe pulmonary hemorrhage. The scoring system we implemented is simple and straightforward, using degrees of pulmonary hemorrhage familiar to pathologists and most clinicians (absent to severe). Because of our earlier study, we also included information on history and adjudication of Child Protective Services referrals.

In conclusion, pulmonary hemorrhage at all levels of severity occurs in infants whose deaths are due to SIDS, accidental or inflicted suffocation. Thus, pulmonary hemorrhage cannot be used as an independent marker in determining the cause and manner of an infant dying suddenly and unexpectedly. Rather, pulmonary hemorrhage must be interpreted in context with other findings obtained from review of the medical history, circumstances of death, and postmortem examination (for which standardized protocols exist to assist in this endeavor).[30,31] In the presence of grade 3 or 4 pulmonary hemorrhage, careful search for other physical signs including facial petechiae, oronasal blood,[16] pressure marks on the face and neck, or torn labial and lingual frenulae should be undertaken. Finally, use of the 2004 SIDS definition is encouraged to delineate the underlying mechanism(s) of death in SIDS.

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